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# Discharge/Stage Relations in vegetated Danish Streams

by

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Abstract

This paper describes how the friction in Danish streams varies as function of the vegetation. The major species of vegetation are presented. A series of laboratory and field experiments are described, and a hypothesis for the influence of the vegetation on the Manning's n is discussed.

## Introduction

Danish streams are all typical lowland streams, since the country are totally devoid of rocks or mountains. The streams are meandering through glacial deposits of moraine clay in the eastern part of the country and more sandy soils in the western part. Although the streams are comparativily small most of them have a stable waterflow through the year. The surroundings are almost entirely agricultural land, mostly pastures for cattle.

Fifty ore more different species of macrophytes make up the flora of these streams, but only few are quantitatively important. Among those the sibling species of *Batrachium* or the two monocotyledonts *Glyceria maxima* or *Sparganium simplex* are dominant. *Helodea canadense* or species of *Callitriche* are subdominant with either of the dominant vegetation types.

Due to intensivation of farming methods during this century macrophyte growth in streams has become a severe problem. The heavy growth of plants rises water levels and causes draining systems to stop working and yields from farming to fall drastically. This effect has been accentuated by channalisation of streams making the water systems even more subsebtible to macrophytes than before.

Public authorities are responsible for removal of macrophyte vegetation in almost all the streams. Untill now this have been done by cutting the weeds 1-4 times a year. The removal has always been done by clear cutting, and due care was taken not to leave any vegetation.

The consequences of clear cutting were dramatic alterations of water levels from situations with a dense vegetation to situations without any plants.

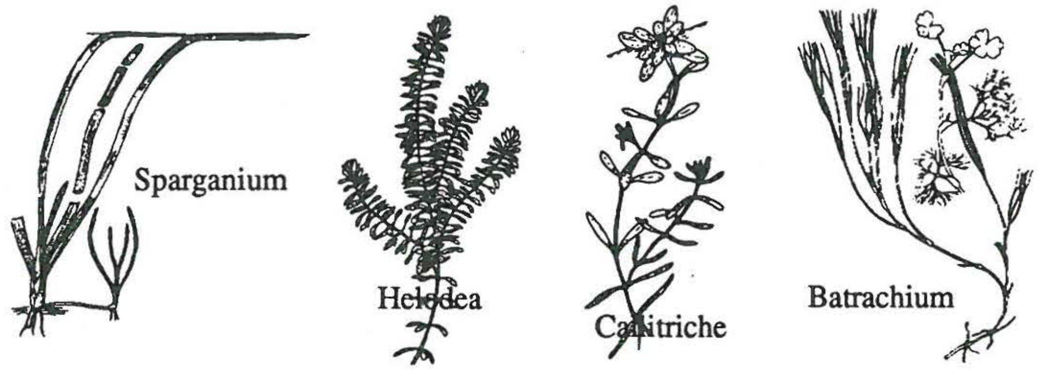


Fig. 1. Dominant species of vegetation in Danish streams

Most danish steams are polluted to some extent either from sewage plants or from trout farms. The big variation in vegetation density during the summer caused organic matters to degrade over either a very short (dense growth) or a much longer (no growth) length af water. This made oxygen levels fluctuate between intolerable and tolerable levels .

Through interaction with the carbonate system of the water macrophyte growth makes the streams more alkaline. The old management practice for vegetation caused bigger fluctuations in pH than necessary, sometimes making the environment dangerous to stream animals.

Most invertebrates in the streams, especially stoneflies (Plecopthera), mayflies (Emphemerida), and dragonflies (Trichopthera) are delimited in their distribution by the unfavourable oxygen levels and unfavourable pH levels of danish streams caused partly by the above mentioned clear cutting practice for the vegetation management. In addition the method in most cases causes the animals to live in suboptimal densities, because they found themselves in surroundings fluctuating between lots of food and practically no food, between no shelter and ample hideaways.

The commercially most important non salmonid fish in danish streams are eels. Like other fishes they have been moving around in the streams due to the fluctuating oxygen levels in the environment. The exact effect of this phenomenon is not well known.

The salmonid fishes (mostly trout) are teritorial during their stream life, and their moving around due to oxygen fluctuations and cover removal causes suboptimal population sizes of these fishes.

New methods for weed removal have been developed during the last decade. The vegetation are cut during the whole summer to avoid fluctuations in water levels and in biological important water parameters. Clear cutting is also avoided, by regular thinning or channel cutting through the vegetation. The ultimate goal for the management practice is a constant water level and constant and favourable biological conditions in the stream in conjunction with a permanent function af the agricultural draining systems.

Optimal strategies for weed management calls for rigid hydralic tools for estimation of the effect on water level and water flow from various stands of underwater vegetation.

The objektive of this paper is to provide some of the basis for such tools by means of a combination of mathematical models, experiments in artificial channels and measurements and experiments in nature.

## Materials and methods

The field experiments was caried out in Herredsbækken, a smaller stream near the city Aars in the nothern part of Jutland. The chosen reach is approximately 150 m long, 2-2.5 m wide. The cross section is almost rectangular. The bottom slope is 0.1-0.2 percent and during the period of measurement in september 1989 the discharge was approximately 100 l/sec. The average depth was between 0.2 and 0.4 m (see figure 3).

The reach in Herredsbækken was densily covered with weed totally dominated by *Sparganium simplex*. The biomass of the weed was measured as wet weight and was found to 2.38 kg/m$^2$ for the upper reach and 1.55 kg/m$^2$ for the lower reach. The percentage dry matter was found to 7.4 %.

| | Dry weight g/m$^2$ | Dry matter % |
|---|---|---|
| Flume tank eksperiment, density I | 390 | 4 |
| Flume tank eksperiment, density II | 190 | 4 |
| Flume tank eksperiment, density III | 80 | 4 |
| Sparganium simplex - Herredsbæk - September, Area 3 | 120 | 7.4 |
| Sparganium simplex - Herredsbæk - September, Area 6 | 180 | 7.4 |
| Batrachium sp. - Gryde Å - July, August | 200 | |
| Batrachium sp. - Gryde Å - Winter | 40 | |
| Batrachium sp - Simested Å - May, Average of 6 areas | 48 | 5.0 |
| Batrachium sp. - Fjederholt Å - July, Average for 2 summers | 350 | |

Fig. 2. Biomass density of plants in our eksperiment and in typical situations in Danish streams. Result from Gryde Å are from Jeppesen and Thyssen (1985). Result from Fjerderholt Å are from Kern-Hansen et al (1980). The rest are own measurements.

The water level was measured in 7 stations, and the flow was found by "velocity area integration", where the velocity was measured in a number of point in the cross section near station no. 3. Approximately 600 m upstream the brook widens into a lake with a 20000 $m^2$ large surface. By controlling the outlet from the lake by a weir, the discharge at the reach could be varied in the range from 80 to 450 l/sec.

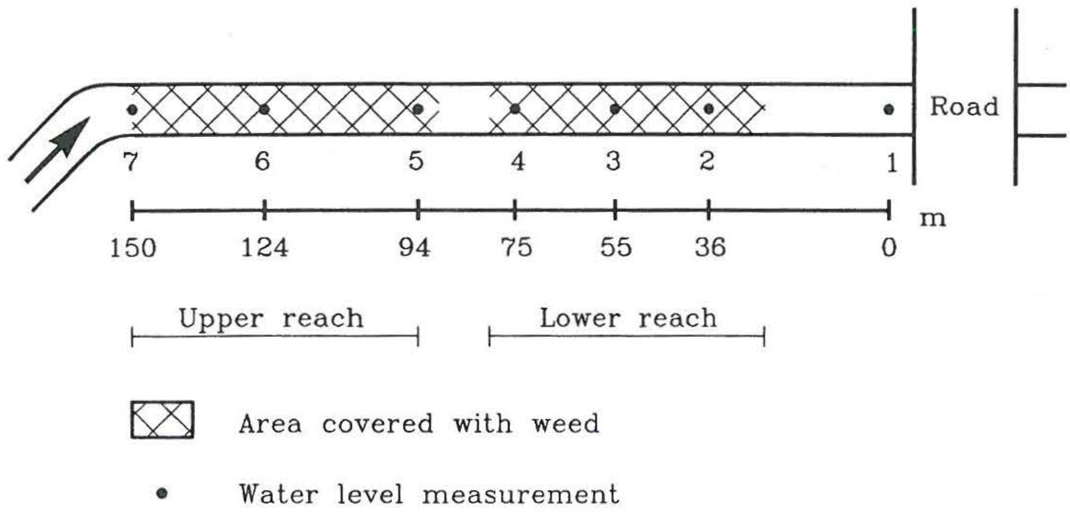


Fig. 3. The reach i Herredsbækken

The results was discharge-depth series for each station. Using a backwater calculation it was possible to obtain the Manning coefficients for each flow-series.

The flume tank experiments in the laboratory at the University of Aalborg was carried out in a 15 m long rectangular flume tank with a width of 30.5 cm.

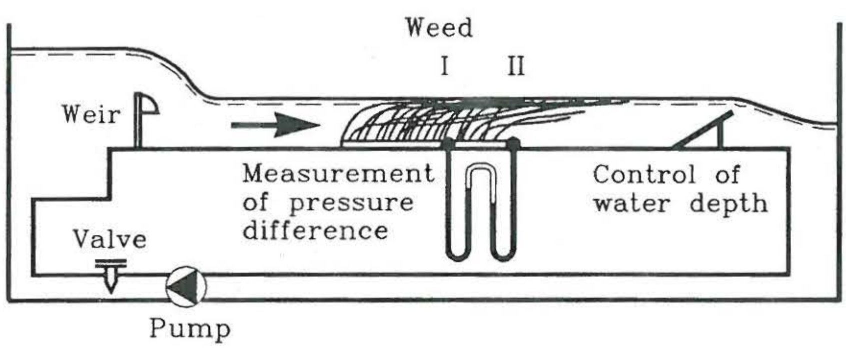


Fig. 4. Flume tank eksperiment

Discharge/stage relations in streams

In this flume tank a 1.5 m long reach with weeds of *Sparganium simplex* was buildt. Each stem was fixed in a net of metalwire, which afterwards was founded in plaster. The average length of the weed was 81 cm, the specific gravity 802 kg/m$^3$, and the percentage dry matter 4.0 %. The biomass densities of *Sparganium* covered the ranges normally found in Danish streams (see figure 2).

The discharge could be controlled by a valve and was measured by use of a sharpcrested weir. The discharge could be varied in a range from 1 to 18 l/sec. The slope of the water surface was measured as a difference in pressure between point I and II (see figure 4). The distance between point I and II was 61.3 cm. The water depth was measured in point I and could be varied in the range from 6 to 22 cm.

The slope of the water surface was measured for a large number of combinations af discharge and depth, then the density of weed was decreased by removing approximately half of the straws, before the measurements were repeated. Measurements were performed for four different densities of weed, and from a backwater calculation the Manning coefficients was found for each combination of discharge, depth and density of weed.

Hydraulic considerations and results

The main objective of this work was to establish and discuss methods for the determination of discharge/stage relations for vegetated streams. Especially it is relevant to evaluate the flooding risk for streams in the summer period in connection with uncommon high discharges. A typical discharge/stage relation is shown in figure 5.

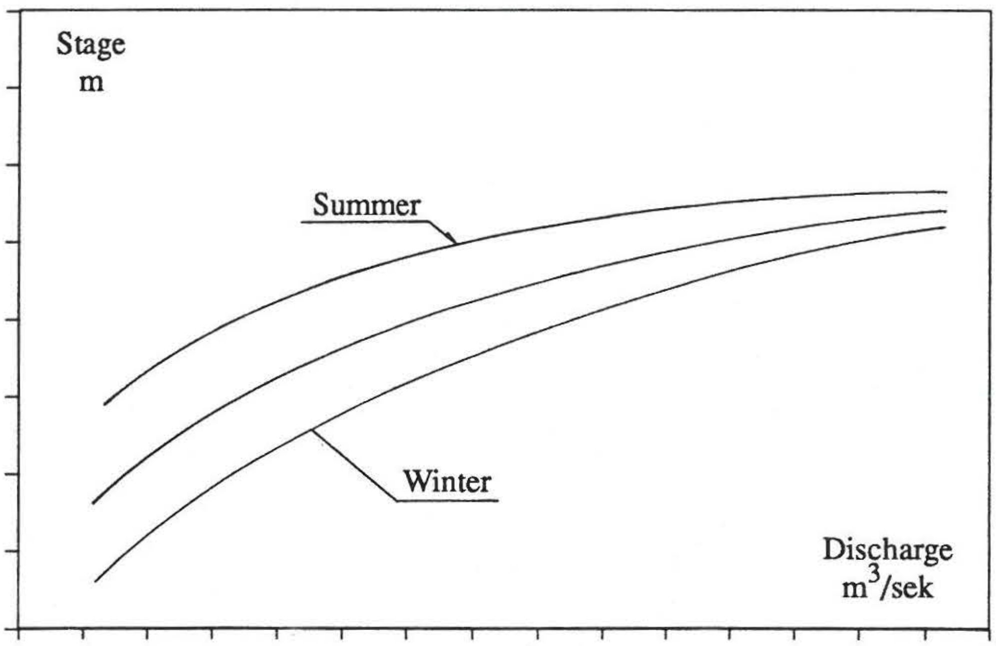


Fig. 5. Discharge/stage relations for a stream with vegetation

It is a general accepted fact that the friction in vegetated streams and rivers depends on the discharge rate, see e.g. (Chow 1959). Many words could have been spent on discussing which friction equation to use under such circumstances. But this seems to be irrelevant because the physics of the phenomena indicates that a varying friction coefficent would anyhow be nessesary. The friction will here be described as the variation of the Manning's n from the well-known Manning equation:

$$V = \frac{1}{n} R^{2/3} S^{1/2} \qquad or \qquad Q = A \frac{1}{n} R^{2/3} S^{1/2}$$

where
V is cross-section average velocity [ m/s ]
Q is discharge [ $m^3/s$ ]
A is cross-section area [ $m^2$ ]
n is Manning's n
R is hydraulic radius [ m ]
S is the slope of the energy line [ dimensionless ]

Chow(1959) refers a number of investigations on grassed channels, which show how the Manning's n depend on the product of V• R ( average cross-section velocity times hydraulic radius ).

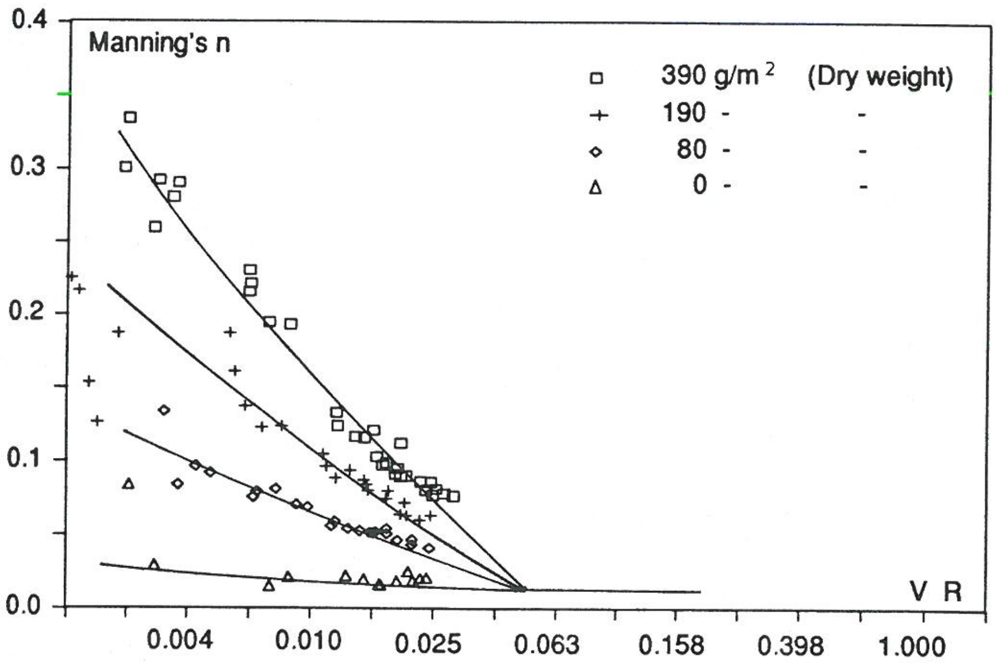


Fig. 6. Results of flume tank eksperiment.

In this investigation different ways of plotting the results was tried. E.g. n was plotted against discharge, velocity, bottom shear etc. But the conclusion was that plotting n against V• R gave the most consistent results (figure 6).

Figure 6 shows the results the laboratory experiments described . This gives a clear picture how the friction increase with vegetation density and decrease with the product of V• R. It should here be repeated that in the laboratory experiments a large number of independent combinations of V and R were tested. The laboratory results confirm that the product V• R is a reasonable variable in the description of the varying n. Furthermore the results make it probable that the curves converge against one point of intersection. For similarity reasons it cannot be expected that the laboratory results can be directly compared with the field experiment.

Details will not be given here, but it should be mentioned, that the head loss for the small discharge part of the laboratory experiments, where the weed covered all the cross section, was almost proportional to the velocity. This indicates that the flexible and slightly moving plants absorb the turbulence to give an almost laminar friction relation.

The results of the field experiments are plotted on figure 7 together with results published by Powel(1979).

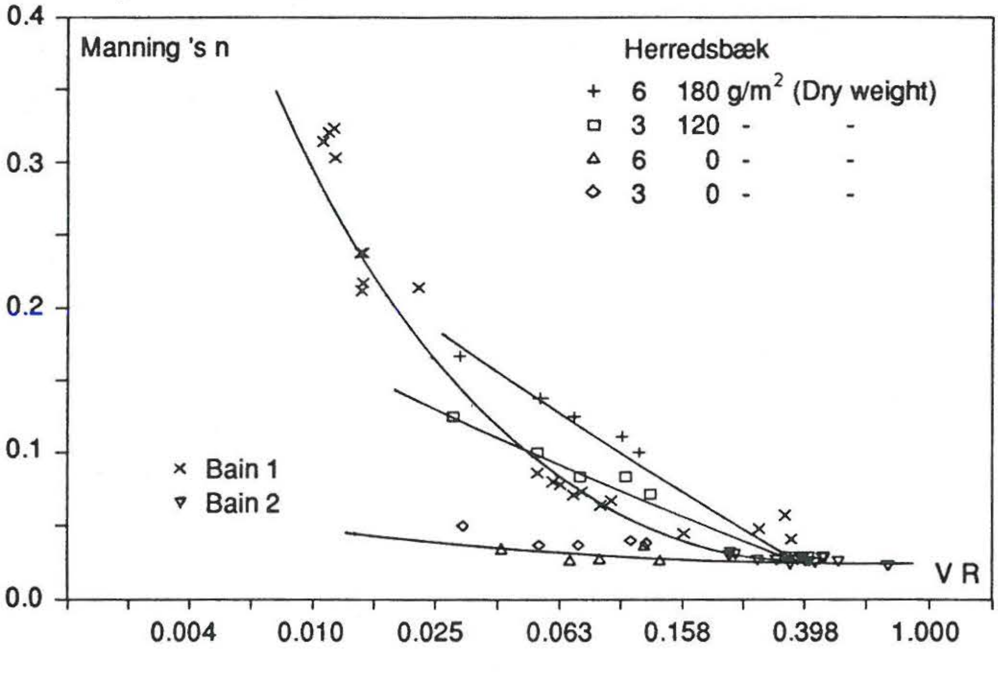


Fig. 7. Results from field eksperiment in Herredsbækken

The results of Powel were measurements from River Bain in U.K. for a short rain period in July 1973, where discharge varied over a range from 0.1 to 6 $m^3$/sec. The vegetation was dense and dominated by pondweed *(Potamogeton pectinatus* and *Helodea canadense)*. It was raported that approx. 70 %of the river surface was covered by weed. The dry weight of the vegetation was not measured

The field results from U.K. and Denmark show the general dependence of the Manning's n in respect to the product of V• R. In this case V and R were almost 100 % correlated because of the unique discharge/stage relationship during the measurements. This means that the field measurements do not confirm that V• R can be used in general, but fortunately the laboratory results were quite clear on that point.

As a working hypothesis it seem to be probable that the curves have a common point of intersection for a value of V• R= 0.4 $m^2$/s. If this can be taken as a general value for streams of the actual size and type, which covers a wide range of Danish streams, a discharge/stage relation can be established from the basic winter relation and supplemented with one discharge/stage measurement at the actual time. Figure 8 illustrates this principle.

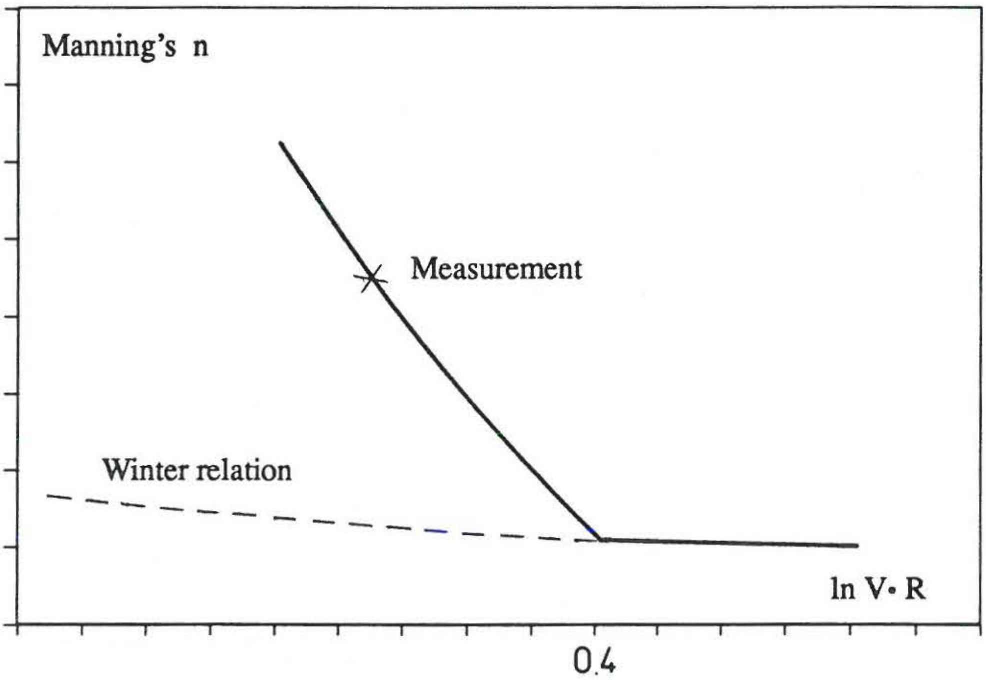


Fig. 8. Actual Manning's n.

In this investigation it was tried, but without succes, to characterize the friction also on the basis of typical plant characteristics with parameters like the dry weight per unit stream bed area (or volume), the plant surface area per stream bed area or the like. A temporary conclusion on this point is, that the actual Manning's n up till now, is the best parameter to characterize the vegetation in this respect. On the other hand the empirical approach taken here can without doubt be improved based on further similarity considerations combined with more data.

## Conclusion

This investigation confirm that vegetation has a significant and often dominating influence on the hydraulic friction in streams. But the effect decrease and even vanish under high discharge conditions. There seems to be a clear relation between the Manning'n and the actual product V• R of average velocity and hydraulic radius. For discharge conditions, where V• R is greater than 0.4 $m^2$/sec, the friction is no longer influenced by the vegetation. From these general observations, it is possible to establish an actual discharge/stage relation in the vegetated period, based on only a single set of measured discharge/stage values.

Because the functional description of the variation of Manning's n use V• R as the independent variable, the relation is valid not only for uniform flow, but also for backwater and unsteady calculations.

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